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# Modeling of HEL Weapons in Army Combat Simulations

**OPERATIONS RESEARCH CENTER OF EXCELLENCE**
**TECHNICAL REPORT [DSE-TR-03-02]**
**DTIC #: ADAXXXXX**

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The Operations Research Center of Excellence is supported by the
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# Abstract

As part of the Joint Technology Office (JTO) High Energy Laser (HEL) Modeling and Simulation (M&S) study, we conducted an inventory and evaluated existing HEL M&S capabilities of Army combat M&S software packages to judge their applicability, utility, and limitations with respect to modeling HEL weapons. Based on that survey and the unique Army requirements for modeling HEL weapons in ground warfare and air and missile defense scenarios, we narrowed our focus to a few of the existing models. On those models, we conducted a software study to determine the issues, implications, and limitations of integrating HEL weapons into the selected software packages. We conclude with a refined roadmap for future research in this area.

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# Acknowledgements

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# Chapter 1. Introduction

The HEL JTO is coordinating the services' efforts to develop high-energy laser weapons. As part of this effort, the JTO recognized the need for end-to-end modeling of such weapons. Physics-based models exist for laser generation, beam formation and control, atmospheric propagation, and target interaction, but the JTO has no available model for a complete laser weapon shot ("photon birth to death"). Higher-level models of a military engagement, the execution of a military mission, or the carrying out of a campaign involving HEL weapons are also unavailable. It is clear that low-level, very detailed, physics-based models need to be linked in some way to higher-level engagement, mission, and campaign models, but it is unclear how this linkage should be worked.

To fill this gap, the HEL JTO asked the two service graduate schools of engineering (Air Force Institute of Technology (AFIT) and Naval Post Graduate School (NPS)) and the three service academies, United States Military Academy (USMA), United States Naval Academy (USNA), and United States Air Force Academy (USAFA), to form a consortium to research what modeling is required and to develop a model or family of models to meet the JTO's needs. AFIT agreed to lead this effort and the other institutions agreed to participate in ways appropriate to their capabilities and areas of responsibility.

The objectives of the effort are: (1) to develop a tri-service research team to integrate Department of Defense (DoD) fundamental research in end-to-end HEL modeling; and (2) to develop a government-owned, DoD-accepted global interface, which integrates existing and future HEL models. The initial focus must achieve a balance between (1) on-going, high-fidelity technical analyses, (2) engineering trade studies, which allow analyses of a wide range of systems, not simply a deep analysis of any one selected system, and (3) analyses of HEL systems' military utility against a broad range of missions.

The lion's share of the effort will be with AFIT, as the institution with by far the greatest expertise and experience with HELs. The participation of USMA will primarily be in evaluating how HELs are or should be modeled in ground warfare and air and missile defense scenarios, and in helping develop linkages from physics-based models to higher-level engagement, mission, and campaign models.

In consultation with the other participants, AFIT has defined a three-phase program:

Phase I (12 months): Define Modeling and Simulation Architecture

Phase II (24 months): Modeling Development

Phase III (24 months): Modeling Expansion

This paper covers USMA's contribution to Phase I. This phase comprises the following seven tasks, which are listed with the proposed USMA contributions:

**Task 1:** AFIT will serve as COTR for JTO M&S Contractual Efforts (no USMA component)

**Task 2:** Inventory and Evaluate Existing HEL M&S Capabilities

(a) Examine existing Army engagement and mission models to identify existing HEL modeling capabilities and determine ownership, utility, and limitations

(b) Identify places in existing models where models of HEL weapons would fit

(c) Obtain, execute, and evaluate codes where appropriate

(d) Document existing capabilities and gaps

**Task 3:** Define and Evaluate Potential HEL M&S Architectures

(e) Research lasers and laser weapons effects to define key modeling parameters for Army applications

(f) Evaluate data aggregation techniques to model HELs in Army engagements and missions

(g) Build simple prototype models to test modeling architecture concepts

(h) Assess candidate M&S architectures for modeling of Army scenarios

**Task 4:** Define Engagement Scenarios

(i) Define key candidate Army HEL platforms, systems, targets, scenarios, and environmental factors. Consider both offensive and defensive scenarios (attack with HEL, defend against HEL)

**Task 5:** Select M&S architecture(s) for Phase II development

**Task 6:** Evaluate potential graphical user interfaces (GUI's)

**Task 7:** Refine Phase II and III Roadmaps

(j) In conjunction with the other members of the consortium, plan approach to Phase II.

# Chapter 2. Problem Statement

This report addresses Task 2 of USMA's contribution to Phase I of the HEL modeling effort led by AFIT for the HEL JTO, as described in the Introduction. Thus, this report is to inventory and evaluate existing Army HEL modeling and simulation capabilities. This includes establishing which Army models have usable HEL models, and then determining their ownership, utility, and limitations.

# Chapter 3. Inventory and Evaluation of Existing HEL M&S Capabilities

Our study began with a report completed in November 2000 by Julianne Pannell of TRAC-WSMR, *Analysis of the Military Utility of Directed Energy Weapons (DEW) in the Extended Area Air Defense (EAAD) Mission: A Combat Model Survey.* Though this report covers all directed energy weapons, not just HEL, and is concerned primarily with the air defense mission, we found that it gave excellent coverage of our area of investigation as of its publication date. Table 1 shows the summary of that study's findings. Thus, our study concentrated on bringing the Pannell study up to the present and on adding more detail on how the identified HEL models are constructed. We did this by web and document searches on the various models, by review of model documentation, and by telephone interviews with the model developers and proponents.

| Model | Scenario Level Modeled | EAAD Target Relevance | Ground Survivability | DEW Capability |
|---|---|---|---|---|
| BEWSS | Brigade and Below | C | C | U |
| CASTFOREM | Brigade and Below | C | C | E |
| CEM | Theater | C | R | R |
| EADSIM | Theater | C | R | C |
| EADTB | Multilevel/Theater | C | C | C |
| JFAS | Division and Below | C | C | U |
| FireSim | Corps/Division/Theater | R | C | U |
| Janus | Brigade and Below | C | C | U |
| JCATS | Multilevel | C | C | C |
| IDEEAS | Brigade and Below | C | C | U |
| VIC | Corps/Division/Theater | C | C | E |
| C = ▢ = Demonstrated Capability<br>E = ▢ = Demonstrated Capability That Will Require Enhancement<br>U = ▢ = Potential But Undemonstrated Capability<br>R = ▢ = Incapable or Major Deficiency | | | | |

**Table 1. Summary of Model Survey Findings (Pannell, 2000:20)**

We found that most Army combat models have no current capability to model HEL weapons. These models are briefly discussed in Section 3.1. Of course, an HEL capability could

probably be added to any of these models if the required analytical and software development work was done.

Two models, CASTFOREM and VIC, had basic laser weapon modules added in the 1980s, but these capabilities have not been used or maintained in 10-20 years and would need significant work before being put into use now. These two models are discussed in Section 3.2.

Three Army combat models have current usable HEL weapon models: JCATS for ground engagements, and EADSIM and EADTB for air defense engagements. These models are discussed in more detail in sections 3.3, 3.4, and 3.5, respectively.

## 3.1. Army Combat Models without HEL Models

We refer the reader to Pannell for more information on the following combat models, which were found to have no capability to represent HEL weapons:

- BEWSS
- CEM
- FireSim
- IDEEAS
- Janus
- JFAS

Since the Pannell study, the following two additional models have started development, without any plans to include HEL models in them:

- Combat XXI
- OneSAF

COMBAT XXI is an object-oriented, HLA-compliant follow-on model to CASTFOREM (see Section 3.2). It is to be a joint model serving all services and joint units.

According to the Fort Leonard Wood Simulation Center:

> OneSAF will be the Army's entry-based simulation for training brigade and below forces beginning in FY 04. It will allow virtually any type Army brigade to train any and all required missions in a realistic manner, in both a stand-alone mode or in a distributed exercise event. When combined with Warfighters' Simulation (WARSIM) and the Army's manned simulators, OneSAF will allow any Army commander to accurately and realistically simulate all battlefield conditions. By FY 2004 OneSAF will replace both Janus and BBS [Brigade/Battalion Battle Simulation] at MANSCEN [Maneuver Support Center]. The reason is that

> OneSAF provides greater flexibility for training and exercises than does either Janus or BBS. (Fort Leonard Wood, 2003)

OneSAF is object-oriented. More information about OneSAF is available from the homepage for the Program Executive Office for Simulation, Training, and Instrumentation Command homepage.

## 3.2. Army Combat Models with Old Laser Weapon Models

### 3.2.1. CASTFOREM

The Combined Arms and Support Task Force Evaluation Model (CASTFOREM) is a force-on-force stochastic simulation model of combined arms combat at the brigade level and below. It includes several hundred lines of FORTRAN code to model HEL weapons, based on models supplied by AMSO in the 1980s. The laser model includes beam wandering, scintillation, and other atmospheric effects. Despite these detailed computations, modeling HELs did not generally affect execution time to any great degree, because the number of laser shots is typically low. The laser model was last used in 1988. Though the routines remain in CASTFOREM, their interface with the rest of the model has not been maintained, and would need a thorough review and checkout before use.

In the 1990s, CASTFOREM was used for a quick-response study with a very simple laser model. This approach modeled an HEL as a very fast kinetic round whose lethality was a function of range.

### 3.2.2. VIC

Vector-In-Commander (VIC) is a variable-resolution discrete event simulator for corps-level combined arms combat, including ISR, fixed-wing aircraft, and amphibious units, as well as typical Army forces. In the 1980s or 1990s some development work was done to model a family of directed energy weapons, and some methodology was developed. The plan was to use CASTFOREM for feeder data. However, in the end the study was cancelled and the HEL model in VIC was not completed.

## 3.3. JCATS

### 3.3.1. General

In 1997, Lawrence Livermore National Laboratories (LLNL) created JCATS by combining two existing combat modeling software packages. The Joint Conflict Model, an

advanced version of Janus, and the Joint Tactical Simulation software were combined to create what we now call JCATS. The improvements made to the combined software packages are described by the phrase that "every aspect takes physics into account." JCATS contains the analysts workstation, a tool used to evaluate scenarios, and systems and weapons models, thus making it a tool for both training and analysis.

### 3.3.2. Laser Modeling Capability

In September 2001, the NPS conducted a limited verification and validation of the JCATS algorithms, version 2.0.0. The study was conducted by James Taylor and Beny Neta. JCATS contains models of beam weapons, and this study verified the beam weapon algorithms based on documentation submitted by LLNL.

### 3.3.3. Issues

The beam weapon algorithms were developed for a non-lethal weapon system. The parameters used in defining the beam weapon are: minimum range, maximum range, setup time, lay time, lay time per 90 degrees (this is currently not used any of the versions of JCATS through version 4.0.0), tear down time, duty cycle, range parameters, range, beam diameter, and pulse length (sec).

### 3.3.4. Implications

Major software modifications would need to be done to modify the beam weapon into a lethal weapon system. EADSIM contains physics models that replicate a lethal beam weapon. See section 3.4 below for a description of the algorithms and parameters needed to replicate a lethal beam weapon as used in EADSIM.

### 3.3.5. Limitations

JCATS is best used at brigade level and below. It is a great tool for Military Operations in Urban Terrain (MOUT) modeling. JCATS is also useful in the test and evaluation of new and future systems and can be used as a training tool as well as an analysis tool.

## 3.4. EADSIM

### 3.4.1. General

Teledyne Brown Engineering created the Extended Air Defense Simulation (EADSIM) software for the purpose of assessing "the effectiveness of Theater Missile Defense (TMD) and air defense systems against extended air defense threats" (Teledyne, 2003). The software is used

primarily as an integrated analysis tool and as an air defense training tool. The focus of EADSIM is on theater-level scenario modeling.

As a general overview, the EADSIM architecture is divided into three main parts: Simulation Setup, Run-time Models, and Post-simulation Analysis. As the name implies, the Simulation Setup architecture is used to create scenarios and set parameters for the execution of the simulation. The Simulation Setup consists of four modules: Scenario Generation, Scenario Execution, Report Generation, and Map Generation. The Run-time Models are part of the main execution architecture of the software and include the C3I/Decision Model and three Technical Models (Flight Processing, Detection, and Propagation). The Post-simulation Analysis architecture consists of Windows-based Post-processing, Scenario Playback, and Off-line Analysis Tools (Teledyne, 2000:3-1 – 3-7).

### 3.4.2. Laser Modeling Capability

The current EADSIM simulation software has a laser ruleset capable of "representing directed energy weapons (DEWs) on various platforms being utilized against various target types" (Teledyne, 2000:4-306). EADSIM breaks down the laser modeling into two Laser Battle Management Phases – the Target-Select Phase and the Launch/Lase Phase.

The Target-Select Phase models threat assessment and the weapon-to-target assignment. Threat assessment consists of determining which of the platform's tracks the laser is to engage, determining which of the engagements are allowable, and prioritizing the allowable engagements. Weapon-to-target assignment determines which weapon should be used to intercept the threat by determining the time required to destroy the target. Such time computations can either include a calculation based on instantaneous conditions when the laser initiates or consist of propagation through engagement completion using the algorithms used for actual lasing and based on predicted locations of the lasing platform and target. In either case, if the time required is greater than the available lase time, the algorithm will not assign the laser to that target, and will move to the next target in priority (Teledyne, 2000:4-309 – 4-321).

The Launch/Lase Phase models the process from the time that the weapons assignment has been made until the engagement is complete. In the case of an airborne laser (ABL), this phase begins with an assessment of whether or not the aircraft must make a turn-to-target maneuver before engagement. The two maneuvers considered are the angle maintenance and target centroid maneuvers (Teledyne, 2000:4-321 – 4-322).

This phase then accounts for the slew time required to move the laser from a stowed configuration to the target location, using either a single-axis or two-dimensional slew model. The single-axis slew model uses the following parameters to determine the time to slew: angle through which to slew, desired pointing vector, current pointing vector, and average slew rate for the target type. The two-dimensional slew model is a much more complex model that accounts for similar parameters in two dimensions, as well as the relative velocity of the target to the turret, angular velocities and accelerations, and a user-defined jerk dispersion time (Teledyne, 2000:4-322).

Additionally, EADSIM accounts for laser warming and cool-down times, which can occur in parallel with other processes, depending on the engagement situation. Once the laser is slewed onto target and warmed, the model accounts for a settle time to model possible physical phenomena, such as control system dampening or the requirement to take an optics measurement before engaging. The model then models the actual lasing of the target (Teledyne, 2000:4-323).

EADSIM allows for four possible laser states: standby, arm, ready, and fire. User-defined parameters control the transitions between the states (Teledyne, 2000:4-325).

EADSIM determines lethality using one of four modeling options: a fluence-based model, an intensity-based model, an Irreducible Semi-Autonomous Adaptive Combat (ISAAC) model, or a shared object model. The fluence model calculates the rate of energy deposit using the laser's peak intensity at the target normal to the beam, the angle of the aimpoint, a user-specified degrade value, and beam spread. Peak intensity and beam spread can be either single-value inputs or determined from power propagation tables. These power propagations tables store values as a function of the following parameters: altitude of the firing platform and target, range between the weapon and target, weapon and target velocity vectors, and the total amount of time the laser has deposited energy on target (to account for dynamic laser degradations and fluctuations). The fluence model then determines the total amount of energy deposit (fluence) required to destroy a target using a random value draw for the probability of killing the target. Next, the model calculates the total amount of energy deposited on target using the rate of energy deposit (intensity) and the amount of time that the target is lased. The fluence model assesses whether or not the target is destroyed using one of two methods. The first method uses a single-valued probability of kill (Pk) and energy required based on the type of target. The second

method uses a Pk curve as a function of the fluence. A random number draw then assesses the kill (Teledyne, 2000:4-326 – 4-328).

The intensity-based lethality model begins with the same rate of energy deposit calculation as the fluence-based model. The intensity model uses that value, combined with target vulnerability data, to determine the total amount of lase time required to destroy the target. Target vulnerability data is stored in table form as a function of target type, aimpoint, target geometry, laser intensity on target, beam spread on target, and Pk. The model uses clock cycles for each laser shot to accumulate the kill metric by cycle until either the target is destroyed or the engagement ceases. For both the fluence- and intensity-based models, if a target that had been engaged but not destroyed is lased again at the same aimpoint, the kill metric can be resumed where it left off in the previous engagement. However, if the time between shots exceeds the maximum revisit time (based on energy dissipation characteristics) the kill metric is reset to zero (Teledyne, 2000:4-328 – 4-331).

The ISAAC model can only be used for engaging theater ballistic missiles (TBMs) in the boost phase. This external model executes all slewing, warming, settling, lasing, and kill determination calculations necessary and will return to the main program whether or not the engagement is complete or whether the target has been destroyed (Teledyne, 2000:4-331).

The shared object lethality model "allow[s] the user to develop a separate algorithm to process an engagement." One of the capabilities of this model is that it can indirectly account for laser drift on target using operator-specified inputs. These inputs include the rate of drift along the target's body, the number of points that should be evaluated along the target, and distance between those points. Other parameters that can be used to construct the algorithms within the shared object model are: position and velocity vectors of the weapon and the target, target orientation vector, aimpoint (nose, wing, or fuselage), laser peak intensity, beam spread, simulation time, HEL delay, integration interval, and additional user-specified parameters (Teledyne, 2000:4-332 – 4-336).

EADSIM also models the following laser engagement constraints: ability to maintain slew on target, geometry constraints, minimum intensity, dwell time, elevation keep out zone (KOZ), sun KOZ, and friendly track KOZ. For each of these, the user can indicate whether the constraint is an abort criterion or a delay criterion. The elevation KOZ constrains the laser (on a ground platform) to fire only above a specified azimuth in order to clear terrain. The sun KOZ

constraint "defines a blind spot for the sensors on a platform," based on a user-defined angle at the platform level to determine the size of the KOZ. The friendly track KOZ will prevent the laser from engaging in the direction of friendly tracks. The parameters that affect this calculation include the initial reported track error volume, a maximum expected acceleration and velocity, and a safety margin, all bounded by a maximum and minimum angular extent defined by the user (Teledyne, 2000:4-353 – 4-359).

### 3.4.3. Issues

EADSIM has a robust laser modeling capability that has been used in modeling HEL weapons currently in development. It is currently used by United States Army Space and Missile Defense Command (USASMDC) and Program Executive Office (PEO), Air and Missile Defense (AMD) to support directed energy at appropriate levels (Cook, 2003). The software does not explicitly model the laser physics in high resolution, especially regarding beam generation, propagation, and effects on target. Nevertheless, EADSIM accounts for many of the key parameters through tables and user-defined inputs, and, therefore, seems to have the resolution necessary for a combat model. However, EADSIM, by design, is primarily a theater-level simulation package with a focus on air defense that is currently unable to model ground combat at high resolution.

### 3.4.4. Implications

EADSIM has made tremendous progress in integrating laser weapons into a combat simulation and has great potential for continued development. Major modifications would be required to model ground combat at high resolution. However, since EADSIM has already successfully linked to an external model (ISAAC), such linkages may be feasibly pursued to integrate higher resolution ground combat models into a federation.

### 3.4.5. Limitations

As previously mentioned, EADSIM has been designed for theater-level simulations with a focus on air defense. In order to make EADSIM a model that can be used Army-wide for HEL simulations, research will have to be done to determine the best way to integrate high resolution ground combat simulation into the software.

## 3.5. EADTB

### 3.5.1. General

Raytheon created the Extended Air Defense Test Bed (EADTB) software for the purpose of examining air missile defense issues in a family of systems. It is primarily used to conduct detailed analyses of system interoperability. It has an object-based simulation architecture and is capable of multi-level scenario modeling from fire-unit level to theater level (Raytheon, 2003).

In general, the model consists of three main modules: the Common Model Set (CMS), the Experimental Data Set (EDS), and the Specific System Representations (SSRs). The SSRs make the EADTB software unique. They are made up of four components: Thinker, Sense, Communications, and Platform. The components are all numerical-data driven, in that the user enters numerical data or makes selections from menus to model the system. Additionally, the user can modify the rulesets used to make decisions within the Thinker component, allowing greater flexibility. The Platform component governs entity movement (ground, sea, air, and space), weapons carrying and launch, signatures, and damage assessment. The Sense component "can be thought of as a transfer function that accepts truth data as input and generates perceived data as output" (Raytheon, 2002:8). It includes both active and passive sensing in both the optical and radio frequency regimes. The Communications modules "pass perceived data between Thinker modules" (Raytheon, 2002:9), and can be modeled through relatively simple instantaneous communication or more complex, multiple-factor communication networks. The Thinker module "can be thought of as a transfer function accepting perceived data as input and generating action as output" (Raytheon, 2002:9)

The primary functions of the CMS are to support background simulation functions and to support SSRs by supplying routines for special-purpose algorithms. The CMS cannot be modified by the user. The CMS has the same four major categories as the SSRs, with the addition of the Environment category to compute environment effects (Raytheon, 2002:6).

The Experiment Data Set (EDS) "contains all the scenario-specific information not included in the SSRs plus the other user-specified information that is required to execute a run or experiment." This module defines the gameboard, the locations of scenario elements, communications networks, data to be recorded, and the random number seed (Raytheon, 2002:6).

The EADTB software has advanced weather modeling capability accounting for such parameters as standard atmospherics (pressure, wind, humidity, air density, clouds, and speed of

sound), precipitation (snow and rain), clouds (position, size, and density; single layer; precipitation starts at the top), and sun and moon locations. The specification of such parameters is at the same resolution as the terrain (down to 30m). The weather can also be modeled temporally, with a resolution of 1 minute increments (Raytheon, 2002:20).

EADTB also has extensive distributed interactive simulation (DIS) capabilities. Users have already operated this software in conjunction with other constructive and virtual simulations. EADTB is HLA compliant.

### 3.5.2. Laser Modeling Capability

Lasers have been modeled successfully in EADTB. In fact, an airborne laser (ABL) SSR has been certified by the ABL System Program Office (SPO) for use in interoperability studies (Freeman, 2003). The current method of modeling lasers in EADTB uses a work-around through the radar functionality of the model. In general, a specific radar waveform is defined as a laser. The radar "paints" a target, but does not deposit energy. The radar is linked to a weapon defined as the laser, which engages the target and adjudicates the engagement (Jackson, 2003).

### 3.5.3. Issues

EADTB's object-oriented architecture and SSR concept give the software tremendous capability and potential for expansion and continued development. It is currently used by the United States Army Space and Missile Defense Command (USASMDC) and the ABL SPO. The software does not currently model laser physics explicitly. In fact, according the software Executive Summary, detailed engineering models are generally beyond the scope of the model (Raytheon, 2002:13). Also, although the software is capable of modeling from the fire-unit to theater level, it does not contain a high resolution model of ground and combined arms combat. The software has extensive advanced distributed simulation (ADS) capability.

### 3.5.4. Implications

The SSR capability gives EADTB the potential to model laser weapons and to instantiate those weapons onto the gameboard with major revisions to the software. That same capability provides the framework necessary to model ground and combined arms combat at a high level of resolution. Additionally, the capability of the software to allow flexibility in the level of model detail for various entities within the same scenario could be quite valuable for managing size and complexity of the simulations. In depth analysis must be done to determine how laser weapon

SSRs can use the Environment component of the CMS to model laser propagation realistically and whether the terminal effects can be modeled accurately.

### 3.5.5. Limitations

As mentioned already, EADTB is not appropriate for engineering-level representation of lasers. Interested users must take EADTB to the next step to determine if it is a suitable tool by moving from the laser work-around using radar functionality to the development of an explicit laser functionality.

# Chapter 4. Conclusions, Recommendations, and Future Work

The results of this investigation can be summarized as follows: In EADSIM, the Army has a robust and proven HEL combat model for air and missile defense engagements. EADSIM models the physics of laser weapons at a medium level of fidelity. EADTB also contains a usable HEL weapon model for air defense engagements, but at a somewhat lower level of fidelity. However, the Army currently has no usable combat model for HELs in any other mission, such as a direct fire ground-to-ground role.

Since AMD is probably the Army mission for which HELs will first be fielded, it is appropriate that that mission is the one that is well-modeled. As a follow-on to this effort, it would be worthwhile to inquire whether there is a need to increase of level of fidelity in EADSIM, perhaps by adding more detailed physics-based models of beam generation, propagation, and target interaction.

The lack of a HEL combat model for other Army missions is perhaps not very worrisome. HELs are now seldom proposed for ground-to-ground direct fire roles. Until technology advances to the point where HEL systems are much smaller, they are arguably less suited for such roles than traditional kinetic projectiles. Except in a few niche applications, almost all proposed HEL weapon systems have been intended for air, missile, or space targets. In the history of combat models, it seems that a serious proposal for a weapon type comes first, and then a model of it is built for combat simulation. This is the order of things we found in the HEL combat models we evaluated in CASTFOREM, VIC, JCATS, EADSIM, and EADTB. It is reasonable to expect that it will take a serious proposal for a HEL ground-to-ground weapon system to drive the development of a simulation model for such a system.

This result completes the USMA portion of Task 2 of Phase I of the HEL modeling consortium's program (see Section 1). The appropriate follow-on is to go on to Task 3, Define and Evaluate Potential HEL M&S Architectures, and Task 4, Define Engagement Scenarios.

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# Appendix: List of Abbreviations

| | |
|---|---|
| A | |
| ABL | Airborne Laser |
| ADS | Advanced Distributed Simulation |
| AFIT | Air Force Institute of Technology |
| AMD | Air and Missile Defense |
| AMSO | Army Modeling and Simulation Office |
| B | |
| BBS | Brigade/Battalion Battle Simulation |
| BEWSS | Battlefield Environment Weapon System Simulation |
| C | |
| C3I | Command, Control, Communications, and Intelligence |
| CASTFOREM | Combined Arms and Support Task Force Evaluation Model |
| CEM | Concepts Evaluation Model |
| CMS | Common Model Set |
| COTR | Contracting Officer's Technical Representative |
| D | |
| DEW | Directed Energy Weapon |
| DIS | Distributed Interactive Simulation |
| DoD | Department of Defense |
| E | |
| EAAD | Extended Area Air Defense |
| EADSIM | Extended Air Defense Simulation |
| EADTB | Extended Air Defense Test Bed |
| EDS | Experimental Data Set |
| G | |
| GUI | Graphical User Interface |
| H | |
| HEL | High Energy Laser |
| HLA | High Level Architecture |
| I | |
| IDEEAS | Interactive Distributed Engineering Evaluation and Analysis Simulation |
| ISAAC | Irreducible Semi-Autonomous Adaptive Combat |
| ISR | Intelligence, Surveillance, and Reconnaissance |
| J | |
| JCATS | Joint Conflict and Tactical Simulation |
| JFAS | Joint Force Analysis Simulation |
| JTO | Joint Technology Office |
| K | |
| KOZ | Keep Out Zone |

| | |
|---|---|
| L | |
| LLNL | Lawrence Livermore National Laboratories |
| M | |
| M&S | Modeling and Simulation |
| MANSCEN | Maneuver Support Center |
| MOUT | Military Operations in Urban Terrain |
| N | |
| NPS | Naval Postgraduate School |
| P | |
| PEO | Program Executive Office |
| Pk | Probability of Kill |
| S | |
| SPO | System Program Office |
| SSR | Specific System Representation |
| STRICOM | Simulation, Training, and Instrumentation Command |
| T | |
| TMD | Tactical Missile Defense |
| TBM | Tactical Ballistic Missile |
| TRAC | Training and Doctrine Command (TRADOC) Analysis Center |
| TRADOC | Training and Doctrine Command |
| U | |
| USAFA | United States Air Force Academy |
| USASMDC | United States Army Space and Missile Defense Command |
| USMA | United States Military Academy |
| USNA | United States Naval Academy |
| V | |
| VIC | Vector-in-Commander |
| W | |
| WARSIM | Warfighters' Simulation |
| WSMR | White Sands Missile Range |

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